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VII. IMPROVEMENT IN PROPERTIES: REMEDIAL TREATMENTS FOR IMPURITY INDUCED WEAKNESS

Compositional factors that enhance or retard temper embrittlement of alloy steels*

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Temper embrittlement of alloy steels is due to the intergranular segregation of metalloid elements (from Groups IV and VB) under the influence of certain alloy elements or other metalloid elements. Embrittlement can be reduced or eliminated by scavenging reactions between some alloy and metalloid elements. These solute interactions can be rationalized in terms of Guttmann's segregation equation for a ternary solution

$$X_1^{\phi} = \frac{X_1^{\mathrm{B}} \exp \Delta G_1/RT}{1 - \sum_{1,2} X_i^{\mathrm{B}}(1 - \exp \Delta G_1/RT)},$$

where X_1^{ϕ} and X_1^{B} are the equilibrium concentrations of element 1 on the boundary and in the bulk, respectively, and ΔG_1 is the driving force for segregation. A similar equation holds for solute element 2.

The solute interactions can range from strongly attractive to strongly repulsive. If the solutes interact attractively in iron, then both ΔG_1 and ΔG_2 are increased (Guttmann 1976), and this leads to co-segregation of elements 1 and 2. Well known examples are Ni + Sb and Ni + Sn. It is shown that $2\frac{1}{4}$Cr1Mo steel without Ni is not embrittled by 0.04 % Sn (Yu & McMahon 1979). If the attraction is strong enough the alloy element will precipitate, or scavenge, the metalloid (X_1^{B} is lowered). The best known example is Mn + S. It is shown by embrittlement (Yu & McMahon 1979) and surface segregation (Graham & Yen 1979; DiDio & Graham 1979) studies that P is scavenged in steels by Mo, Ti, and Nb, but that the scavenging effect can be defeated by precipitation of these elements by C. The rate of P segregation is then controlled by the rate of carbide formation (Yu & McMahon 1979).

If the solute interaction is repulsive, and if element 1 is more surface-active, or more mobile, in iron than element 2, this can result in a positive ΔG_1 and a negative ΔG_2. Hence, element 1 segregates and element 2 is forced away from the boundaries (McMahon & Marchut 1979). The classical example is C + Si. It is shown that Mn and Si both enhance P segregation in steels (Murza & McMahon 1979), and it appears that the Si + P interaction is repulsive, whereas the Mn + P interaction is attractive.

The physical basis for embrittlement is the reduction in the ideal work of fracture by the metalloid element (McMahon *et al.* 1979). This results in a much larger reduction in the plastic work associated with crack propagation (McMahon & Vitek 1979), which accounts for the large reduction in fracture toughness.

* Extended abstract.

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